TP 5203

CONTAINMENT OF AIR CUSHION WITH WATER CURTAIN: SMALL SCALE EXPERIMENTAL INVESTIGATION

Prepared For:

TRANSPORTATION DEVELOPMENT CENTRE
TRANSPORT CANADA

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Prepared By:

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TDC File No: D1460-49-3
DE File No: C82-153

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MARCH 1984

THE CONTENTS OF THIS REPORT REFLECT THE VIEWS OF THE CONTRACTOR AND NOT NECESSARILY THE OFFICIAL VIEWS OR POLICIES OF THE TRANSPORTATION DEVELOPMENT CENTRE

REPORT DOCUMENTATION FORM

1. Transport Canada Report No.	2. TDC Project No.	3. Recipient's Catalogue No.
TP 5203 E	4953	

4. Title and Subtitle	5. Report Date
Containment of Air Cushion with Water Curtain: Small Scale Experimental Investigation	February 1984
	6. Performing Organization Report No. C82-153
7. Author(s) Dr. A.M. Birk, P.Eng., P.C. Chatterjee, B.Eng.	8. Transport Canada File No. D1460-149-3
9. Performing Organization Name and Address: Davis Engineering Limited, 1481 Cyrville Road, Ottawa, Ontario K1B 3L7	10. DSS File No. ---
	11. DSS or Transport Canada Contract No. 4953
12. Sponsoring Agency Name and Address: Transportation Development Centre (TDC), 1000 Sherbrooke Street West, Suite 2421, Montreal, Quebec H3A 2R3	13. Type of Report and Period Covered: Final, March 83 - Jan. 84
	14. Sponsoring Agency Code 4953
15. Supplementary Notes	16. TDC Project Officer: J.E. Laframboise

17. Abstract

An experimental investigation of a water curtain concept for containing positive air pressures for air cushions is described. The apparatus involved a fan fed plenum which opens to a channel where a water curtain can be generated. When the water curtain is present, the plenum is sealed. Depending on the fan flow and the curtain configuration, positive pressures are maintained in the plenum.

Experiments were performed for varying fan flow, curtain thickness and height, and water velocity. The results indicate that considerable positive pressures can be contained by the water curtain.

18. Key Words	19. Distribution Statement
Water curtain, air cushion, pressure containment.	Limited number of copies are available from Transportation Development Centre.

20. Security Classification (of this report)	21. Security Classification (of this page)	22. No. of Pages	23. Price
Nil	Nil	22	Nil

FORMULE DE DOCUMENTATION POUR RAPPORT

1. Nº du rapport Transports Canada	2. Nº de l'étude — CDT	3. Nº de catalogue du destinataire
TP 5203 E	4953	

4. Titre et sous-titre	5. Date du rapport
Containment of Air Cushion with Water Curtain: Small Scale Experimental Investigation	février 1984
	6. Nº du rapport de l'organisme exécutant: C82-153
7. Auteur(s): Dr. A.M. Birk, P.Eng.; P.C. Chatterjee, B.Eng.	8. Nº de dossier Transports Canada: D1460-149-3
9. Nom et adresse de l'organisme exécutant: Davis Engineering Limited, 1481, chemin Cyrville, Ottawa, Ontario K1B 3L7	10. Nº de dossier — ASC: ---
	11. Nº de contrat — ASC ou Transports Canada: 4953
12. Nom et adresse de l'organisme parrain: Centre de développement des transports (CDT), 1000, rue Sherbrooke ouest, Pièce 2421, Montréal, Québec H3A 2R3	13. Genre de rapport et période visée: Final, mars 83 - jan. 84
	14. Code de l'organisme parrain: 4953
15. Remarques additionnelles	16. Agent de projet — CDT: J.E. Laframboise

17. Résumé

Ce rapport décrit une étude expérimentale d'un rideau hydraulique, conçu de façon à renfermer les pressions sur-atmosphériques présentent dans un coussin d'air. L'appareillage employé pour cette étude consiste d'un plénum, alimenté par une souffleuse et communiquant à l'atmosphère par un passage dans lequel il est possible de créer un rideau hydraulique. En présence du rideau, le plénum est effectivement renfermé. Le degré de pression du plénum varie en fonction du débit de la souffleuse et de la géométrie du rideau.

Les expériences ont été éxécutées en variant les paramètres suivants: le débit de la souffleuse, l'épaisseur et la hauteur du rideau hydraulique, et la vitesse d'écoulement de l'eau. Les résultats de ces enquêtes indiquent que des pressions considérables peuvent être retenues par un rideau hydraulique.

18. Mots-clés	19. Diffusion
Rideau hydraulique, coussin d'air, renfermement de pression.	Une quantité limitée de copies sont disponibles aux bureaux du Centre de développement des transports

20. Classification de sécurité (de ce rapport)	21. Classification de sécurité (de cette page)	22. Nombre de pages	23. Prix
NIL	NIL	22	NIL

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1.0 INTRODUCTION

This report presents the findings of a small scale experimental study conducted under Service Contract 4953 for the Transportation Development Centre (TDC) of Transport Canada. The experiments were conducted to study a concept for containing positive air pressures for air cushions using a water curtain as the containing skirt. The specific application being considered is an icebreaker with an integral fluid cushion bow.

The following pages present the details of the experimental apparatus and the results obtained. Recommendations are made for future work in the area.

1.1 Background

In an air cushion positive pressure is contained by flexible skirts. Fans supply air to the cushion to maintain the pressure. The fan flow rate is dependent on the rate of air leakage through the skirting.

In icebreakers incorporating integrated air cushion bows, practical problems arise due to the harsh environment of the arctic. These severe conditions result in increased skirt maintenance costs and lower skirt containment efficiencies. The water curtain concept involves replacing the fabric skirts with a curtain of high momentum water jets. The water curtain contains the cushion pressure and eliminates many of the practical problems associated with the fabric skirts.

The water curtain concept can eliminate many of the operating problems for the integral fluid cushion ice breakers, however, the operating characteristics of water curtains for supporting pressures are unknown. For this reason a test program was undertaken to study the feasibility of the water curtain concept.

1.2 Objectives

The overall objective of the present experimental investigation was to determine the effectiveness of water curtains for containing pressures in air cushion applications. The specific objectives of the experiments were to:

1) establish whether significant pressures can be supported by a water curtain.

2) establish the functional relationships between the curtain

velocity, thickness and the curtain pressure differential for different curtain geometries.

3) establish the appropriate scaling parameters so that the effectiveness of the full-scale system can be estimated.

1.3 Method

To meet the objectives of the present study a small scale test stand was constructed ($\simeq$ 1:50 scale). The apparatus was designed to represent a small section of a two-dimensional water curtain. Every attempt was made to eliminate curtain end effects (three-dimensional effects).

Using this test apparatus, a number of tests were performed with different curtain nozzle configurations. The tests involved measuring the curtain pressure differential, and water curtain supply pressure for a number of different nozzle sizes and different nozzle-ground spacings. Since this was a preliminary investigation, the nozzle inclination angle was not varied.

2.0 EXPERIMENT

This section presents the details of the test apparatus and the experimental procedure.

2.1 Test Apparatus

The test apparatus was designed to study a section of a two-dimensional curtain section. The main structure of the apparatus consists of a pressurized plenum which opens to a passage in which the water curtain is generated. The passage is the only opening to the surroundings, and when the curtain is present the plenum is sealed off.

Two different plenum pressurization schemes were tested. The first consisted of small diameter hoses delivering regulated high pressure air. This system proved to be inadequate for supplying the air needed to compensate for the air leaking through the water curtains. The second air pressurization scheme involved the use of two "shop vac" vacuum cleaners supplying air through large diameter (approx. 3" diameter) hoses. This second method proved successful. The fan flow rates were controlled using a variable ac supply (0 - 115 VAC).

For generating the water curtains, two different nozzle configurations were considered, a commercially available spray nozzle, as shown in Figure 2-1 and a two dimensional slot jet, as shown in Figure 2-2. The commercially available spray nozzle generated a triangular shaped curtain while the slot jet created a rectangular 2-dimensional curtain. Because of the different curtain shapes the main structure of the apparatus was slightly different for the two nozzles. Figures 2-3 to 2-5 show the apparatus with the spray nozzle mounted and Figures 2-6 to 2-8 show the apparatus with the slot jet mounted.

As was already mentioned, the first nozzle was of a commercially available design. The slot nozzle, however, was of a new design. Figure 2-9 shows the details of the slot nozzle.

Basically, the slot nozzle consisted of a thin walled brass tube with the desired slot gap milled into it. Inside this walled tube was a smaller diameter feeder tube with a .051 inch slot milled into it. The feeder tube was located off the centre-line of the large tube directly opposite the slot in the large tube. The slot in the small tube faced away from the slot in the larger tube. The water was supplied to the small copper tube and through the .051" gap. The water then changed direction and passed through the two diverging channels before passing through

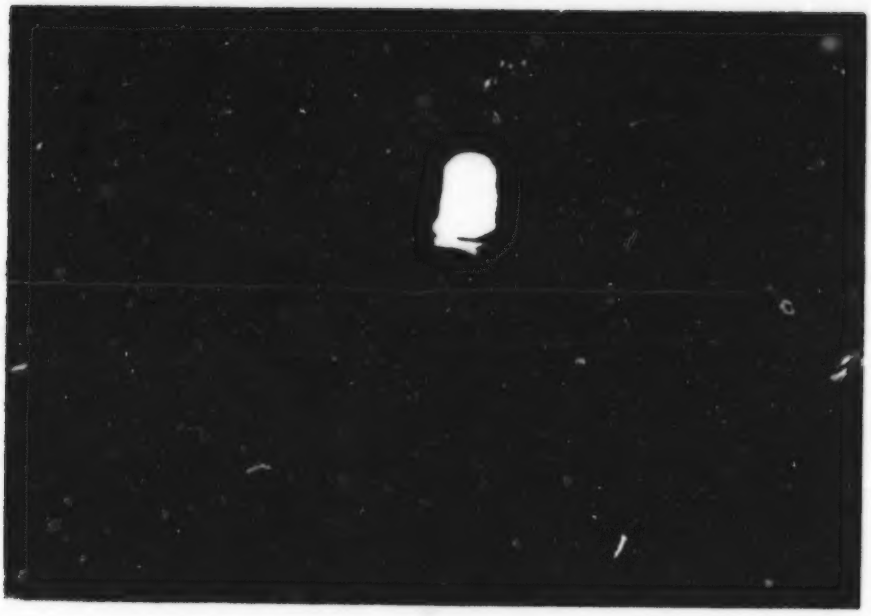

FIGURE 2-1 SPRAY NOZZLE

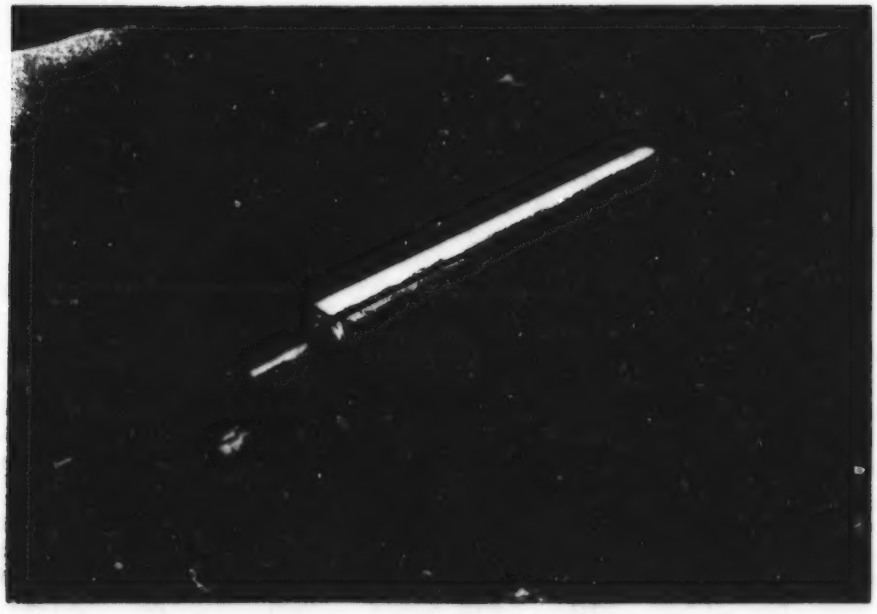

FIGURE 2-2 SLOT NOZZLE

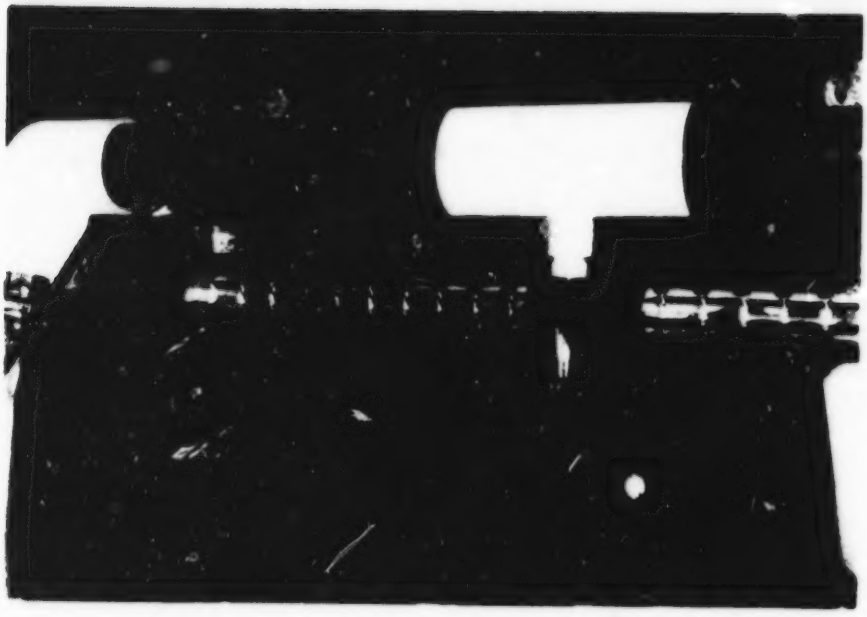

FIGURE 2-3 APPARATUS WITH SPRAY NOZZLE

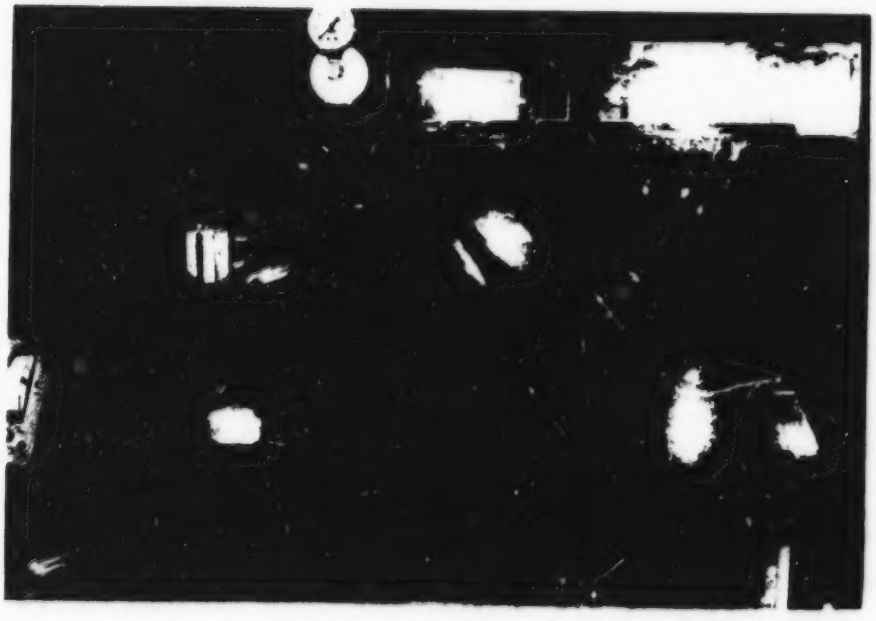

FIGURE 2-4 APPARATUS WITH SPRAY NOZZLE

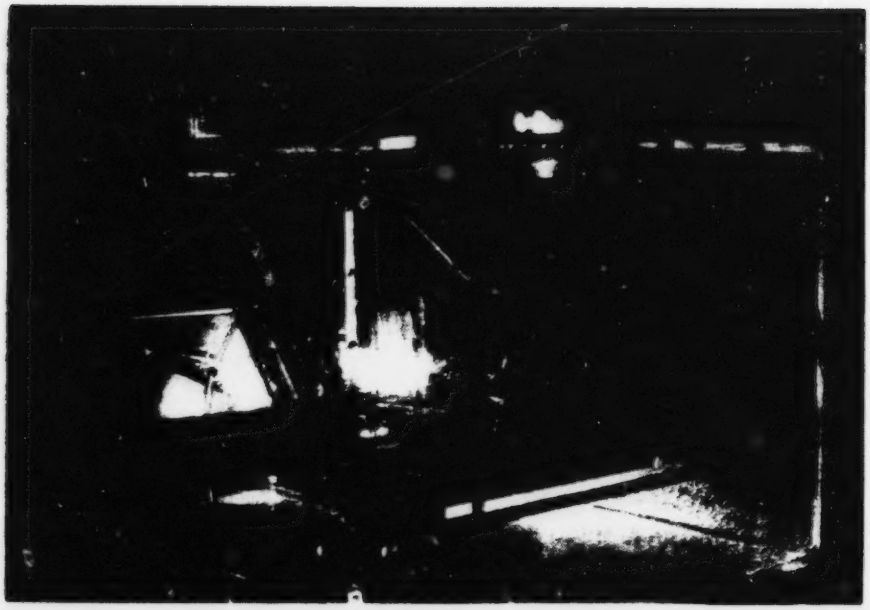

FIGURE 2-5 APPARATUS WITH SPRAY NOZZLE

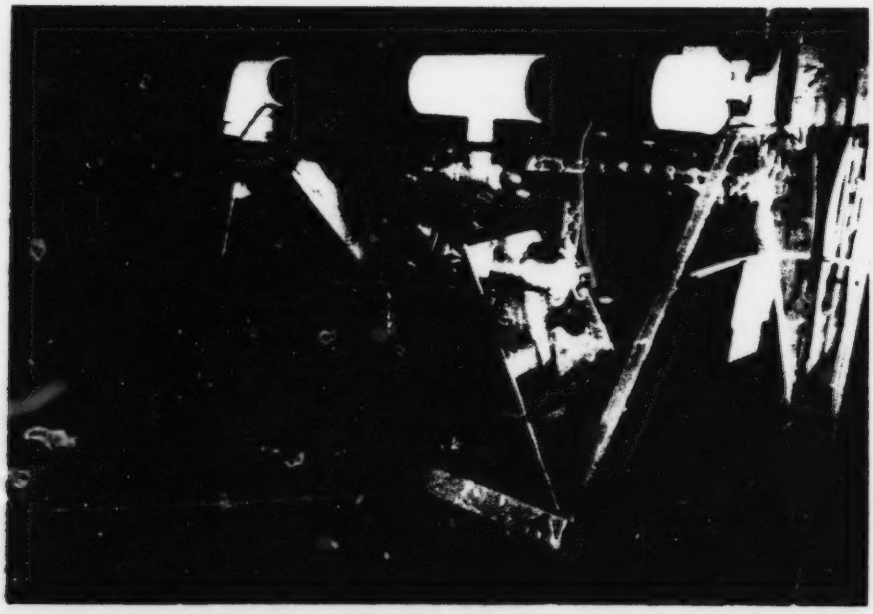

FIGURE 2-6 APPARATUS WITH SLOT NOZZLE

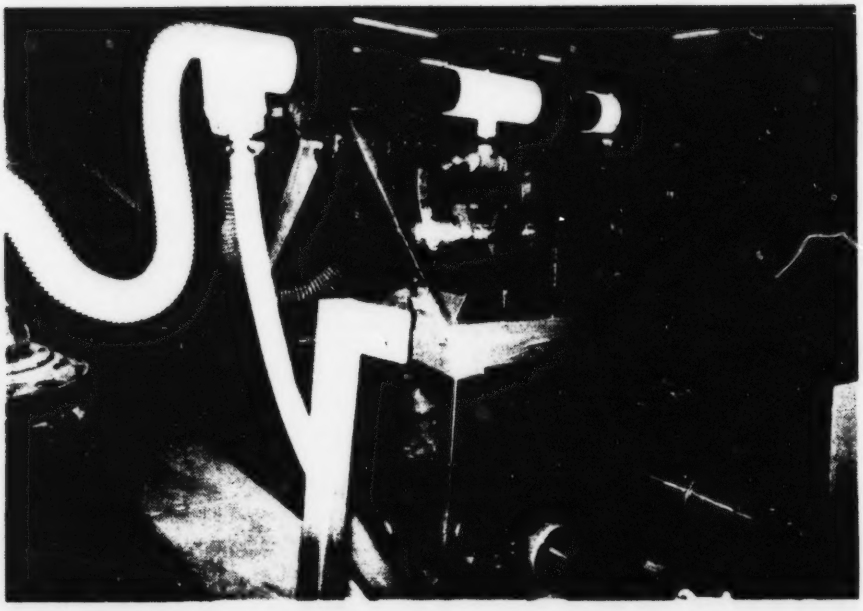

FIGURE 2-7 APPARATUS WITH SLOT NOZZLE

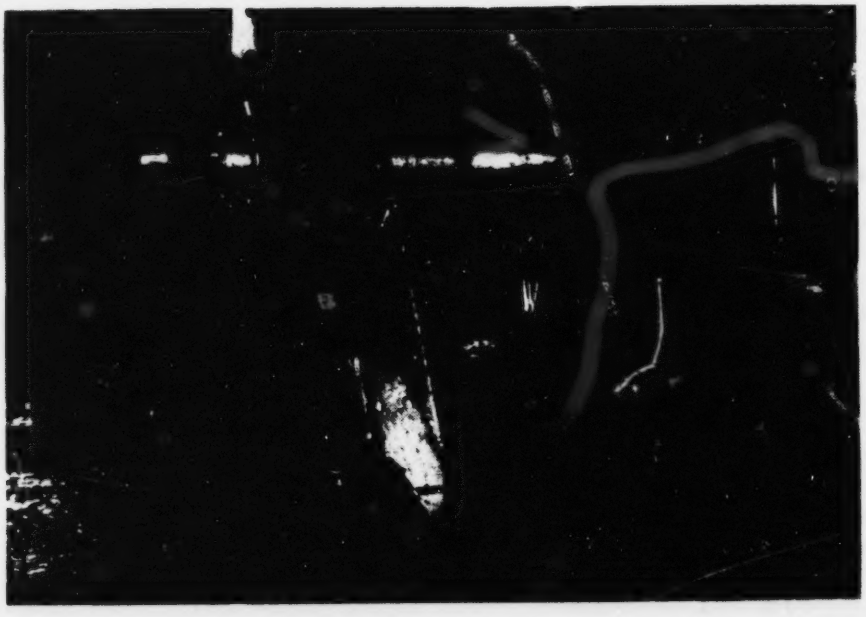

FIGURE 2-8 APPARATUS WITH SLOT NOZZLE

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SUBJECT	SLOT NOZZLE

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ORIGINATOR	
DATE	PG.

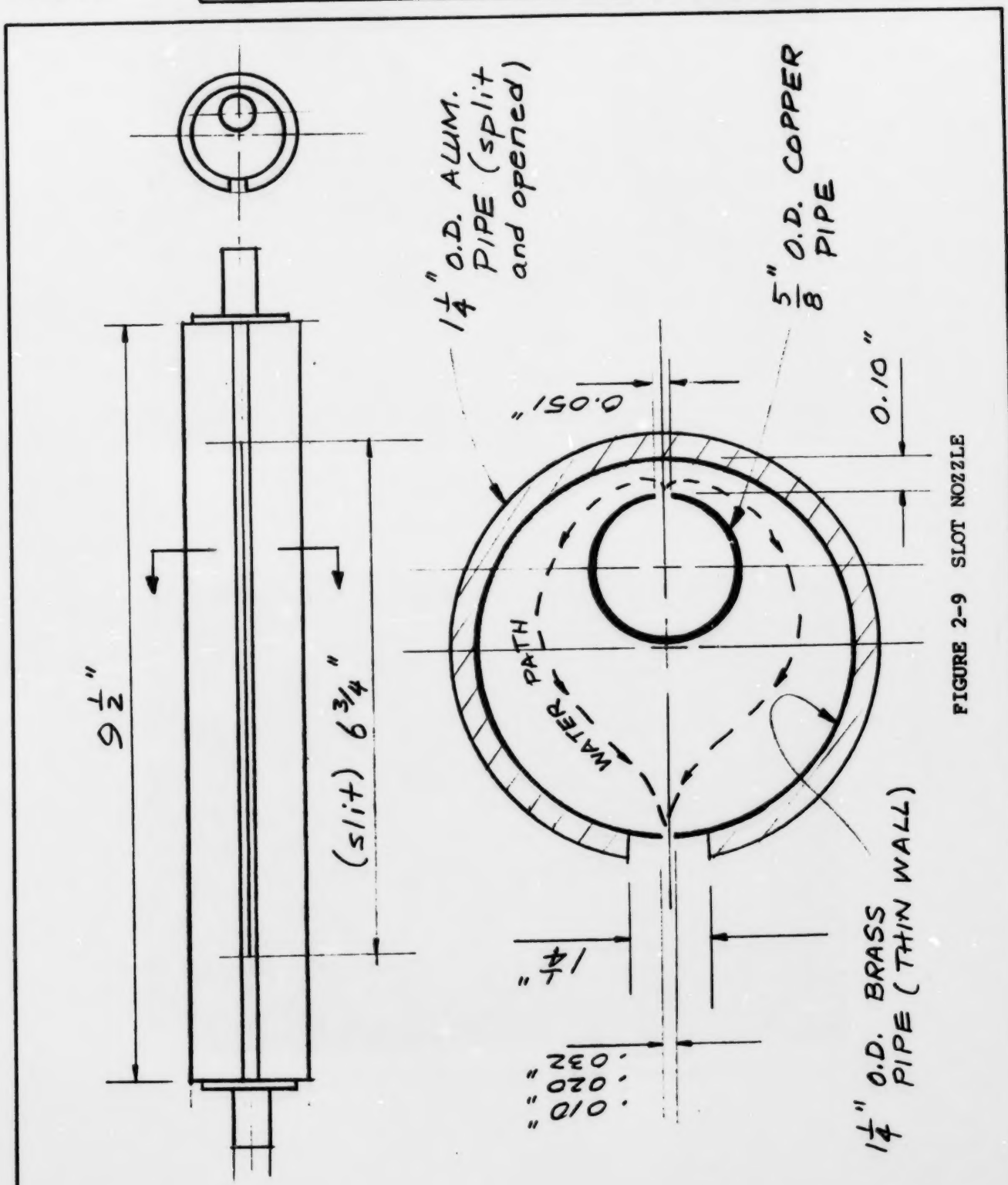

FIGURE 2-9 SLOT NOZZLE

the slot in the larger thin wall tube.

This design was used so that the water flow would be aligned at right angles to the main gap. This would ensure an even, flat curtain. This design evolved from earlier designs which simply consisted of tubes with slots milled into them. These simple designs did not give the desired two-dimensional curtains. In the simple tubes, flow curvature at the ends of the slot resulted in distorted curtains which were unacceptable.

The curtain water was supplied from city water lines and the pressure was limited to the normal city water pressures. The curtain water pressure was manually controlled using a valve.

The experimental instrumentation included a pressure gauge to measure the curtain water supply pressure at the manifold as shown in Figure 2-10. A U-tube and inclined manometer, also shown in Figure 2-10 were used to measure the plenum pressure (ie. the curtain pressure differential). The fan flow rates and the water flow rates were not measured directly using any instruments.

2.2 Test Procedure

The tests were performed using the following procedure.

1) a nozzle configuration was chosen

2) a nozzle/ground spacing was chosen

3) a water curtain supply pressure was chosen

4) a fan flow rate was chosen

5) the curtain pressure differential was recorded

This procedure was followed for the following range of conditions.

slot jet thickness	=	0.010, 0.020 and 0.032 inch
nozzle ground spacing	=	1, 3 and 5 inches nominal
curtain supply pressure	=	4 pressures as available
fan voltage	=	29, 58, 86 and 116 VAC nominal

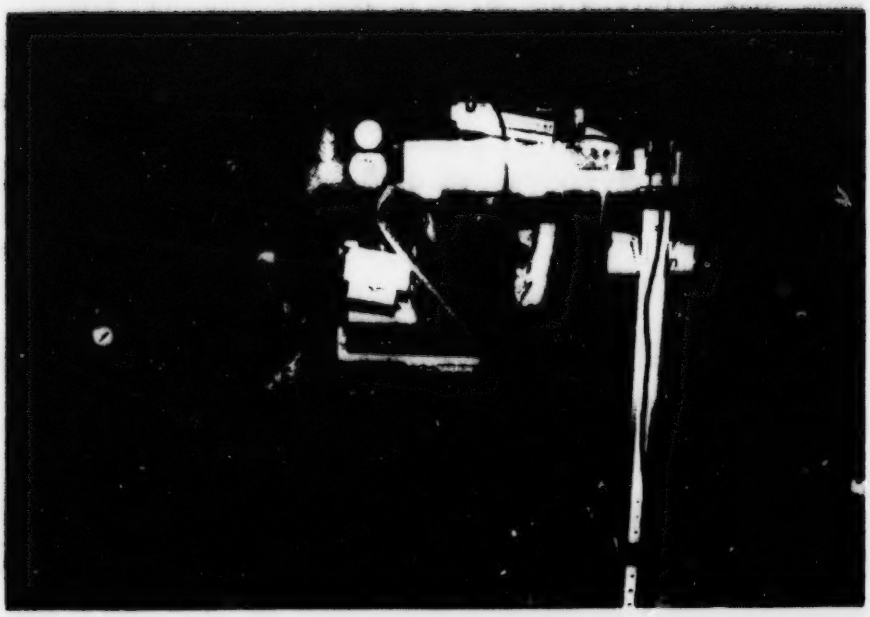

FIGURE 2-10 VIEW OF APPARATUS SHOWING TEST INSTRUMENTATION

3.0 RESULTS

As already mentioned, tests were performed with both a spray nozzle and the slot nozzle. Early in the test program it was found that the spray nozzle arrangement was not performing well and as a result this configuration was dropped from the test program. However, it should be noted that considerable effort was put into getting the spray nozzle configuration to work, with no success.

As mentioned earlier, tests were performed using the slot nozzle with three different gap sizes; 0.010 inch, 0.020 inch and 0.032 inch. Also, three curtain heights were considered. During the tests the water pressure and fan flow rates were varied.

The log sheets containing the raw data from all the tests are presented in Appendix A. The data reduction computer program is presented in Appendix B.

From the raw data on the log sheets it is possible to derive all the information regarding the performance of this small scale ($\simeq$ 1:50) water curtain system, ie. water flow rates, fan flow rates, curtain pressure differential and curtain geometry. In the following pages, only the results for the full fan flow tests will be presented.

The results of most interest in this study are the curtain pressure differential vs. the curtain thickness and the curtain water velocity. This data will indicate whether or not the water curtain concept is capable of supporting adequate pressures for the specific application in mind. Of course, the water flow rates and fan flow rates are also critical in determining the feasibility of the present concept, however, the small scale of the test rig must be considered when scaling the test results to full-scale conditions. This will be discussed further in a later section.

Before the results are presented in graphical form it should be stated that several attempts were made to present the data in non-dimensional form. The following dimensionless groups were considered.

Reynolds Numbers:

$$Re_b = \rho U b/\mu$$
$$Re_L = \rho U L/\mu$$

where,

ρ = water density
U = curtain velocity

b = curtain thickness
L = curtain height
μ = water viscosity

Pressure Ratios:

$$\Delta P_1 = \Delta P_c/\rho U^2$$
$$\Delta P_2 = \Delta P_1 L/b$$

where,

ΔP_c = curtain pressure differential less the air dynamic head when curtain is absent.

When the test results were plotted using these dimensionless groups, the form of the results was not simplified, and therefore it was concluded that there was no advantage in using them at this time. The plots about to be presented, therefore, are in dimensional form.

Figure 3-1 presents the measured curtain pressure differential vs. the curtain water velocity for a number of different slot gaps and curtain heights. Only the data from the full fan flow case is shown. Clearly, the results indicate a complex relationship between the variables. Also, the results indicate that the water curtain can support considerable pressure even at this small scale.

Figure 3-2 and 3-3 present the curtain pressure differential vs. the curtain L/b ratio for two fixed water velocities of 20 and 40 ft/s. These curves were derived from the data shown on Figure 3-1. When the data is presented in this form the functional relationships become more clear. The following observations can be made from Figures 3-2 and 3-3.

i) increasing the L/b causes P_c to decrease

ii) increasing the L causes P_c to decrease

iii) increasing b causes P_c to increase

iv) increasing U causes P_c to increase

v) the water curtain behaves nonlinearly

The implications of these will be discussed further in the following section.

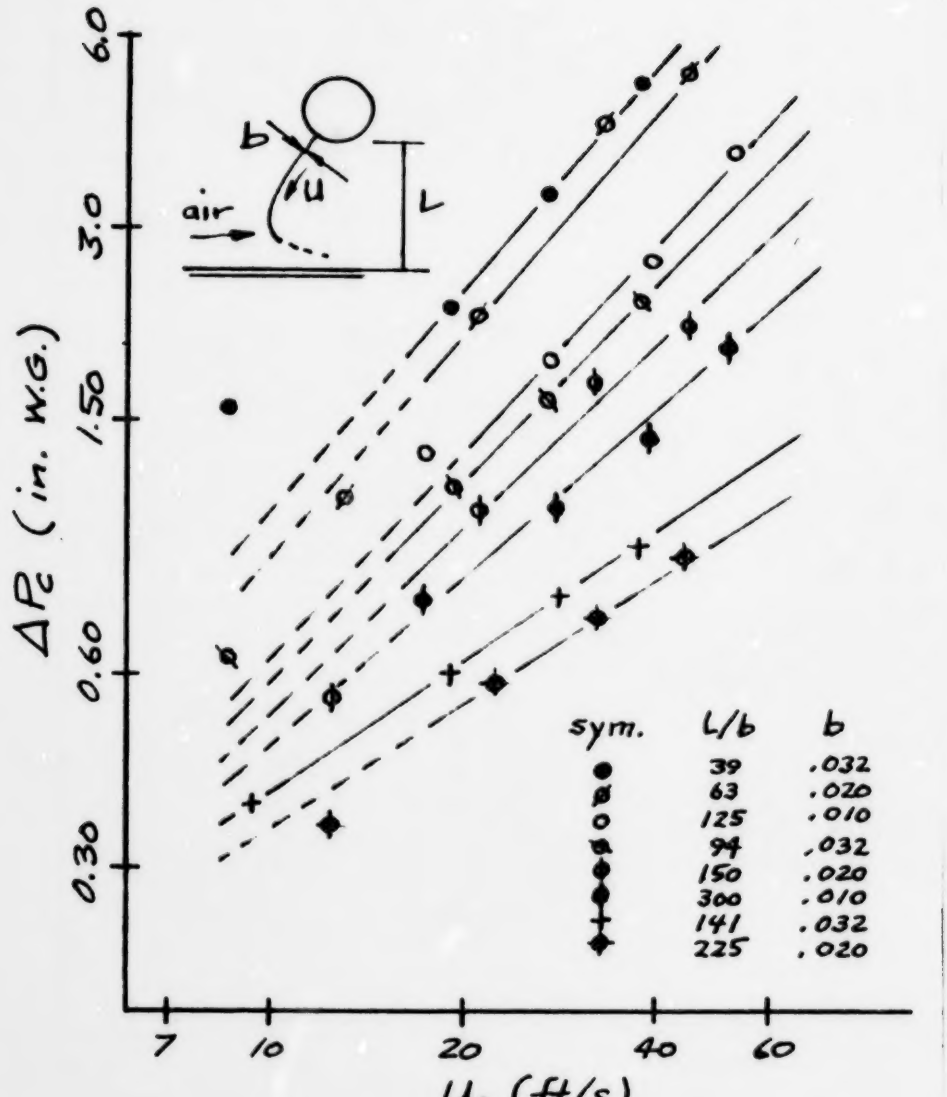

FIGURE 3-1 P_C VS. U_C FOR ALL TESTS WITH FULL FAN FLOW

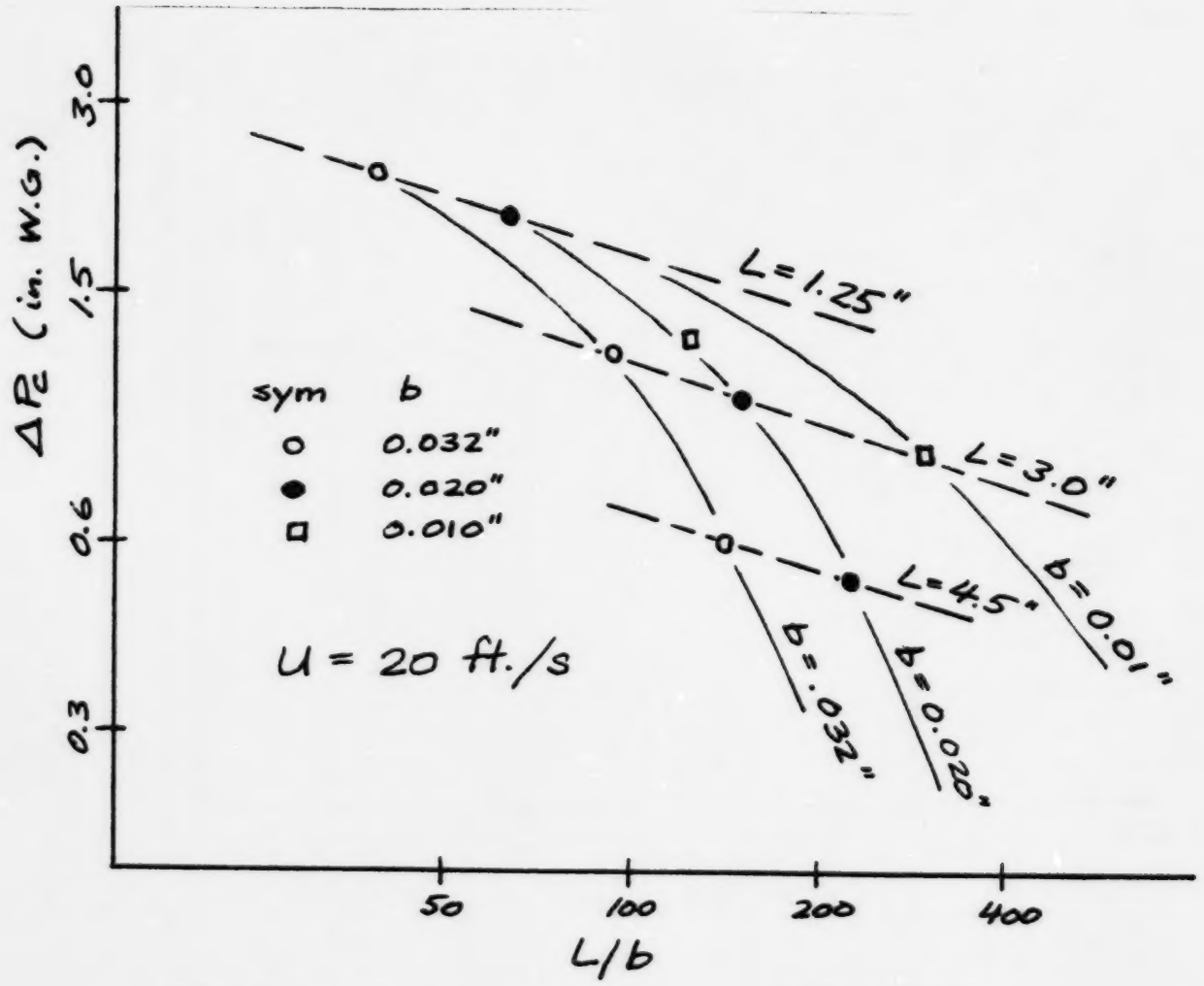

FIGURE 3-2 P_c VS. L/b FOR FULL FAN FLOW AND CONSTANT U_c = 20 ft/s

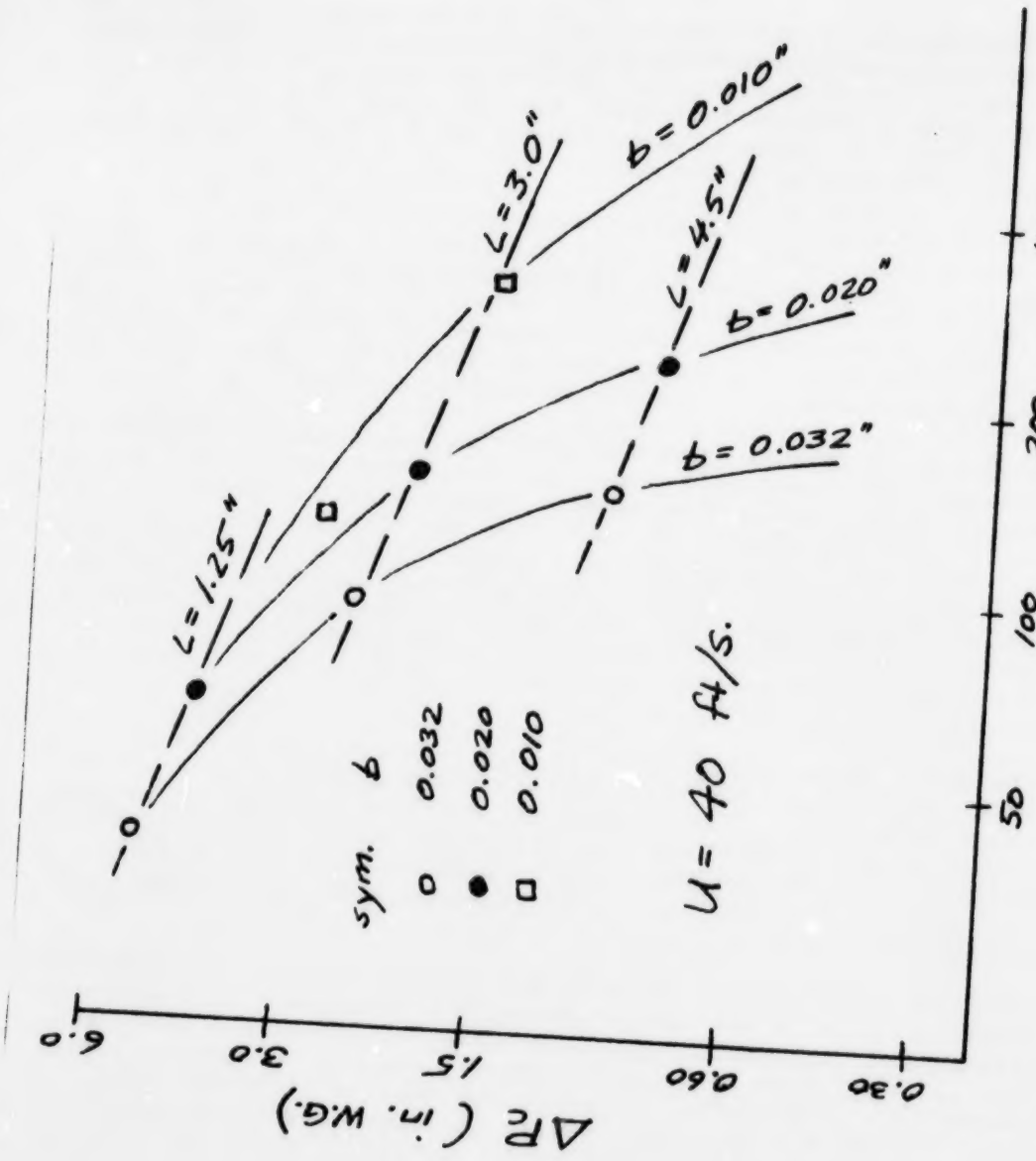

FIGURE 3-3 P_c VS. L/b FOR FULL FAN FLOW AND CONSTANT U_c = 40 ft/s

4.0 DISCUSSION

The results of the small scale tests clearly indicate that it is possible to develop considerable pressure differentials across the water curtain. In the preceding section, a number of observations were made from Figures 3-2 and 3-3. The implications of these observations on a larger scale test facility will now be discussed.

The first observation stated that as the curtain L/b ratio is increased, the curtain pressure differential decreases. This leads us to conclude that it is desirable to keep the L/b ratio of the full scale curtain as small as possible. Of course, the L/b ratio is made up from two independent variables, the curtain thickness b, and the nozzle/ground spacing L. These will be discussed separately in the following paragraphs.

The second observation stated that as the curtain height is increased (holding b, U and fan flow constant) the curtain pressure differential decreases. This can be explained if one recalls the characteristics of free two-dimensional jets, of which the water curtain is an example. With free jets the turbulence increases with down stream distance. As the turbulence increases in the water curtain air entrainment increases and the curtain breaks up. As the curtain breaks up, air leakage increases and the curtain's ability to hold pressure decreases.

Turbulence plays a key role in the curtains effectiveness to contain pressure. As the curtain becomes more turbulent air leakage increases. Therefore, it would be desireable to keep turbulence to a minimum in the full scale water curtain. Possibly, a thick laminar curtain could support larger pressure differentials because of the absence of turbulent air entrainment.

The third observation, stated that as the curtain thickness is increased (holding all other parameters constant) the pressure differential increases. This is due to the simple fact that there is more mass to be deflected by the air pressure. This observation, therefore, supports the earlier statement that a thick laminar curtain may result in more efficient pressure containment than a thin turbulent curtain. This of course, requires further study.

The fourth observation stated that as the curtain velocity is increased the pressure differential increases. This is due to the simple fact that as the curtain velocity increases the momentum increases. It is the curtain momentum that contains the

air pressure. However, high velocity curtains tend to be very turbulent. This was certainly observed during the tests. Generally, the lowest flow velocities rendered clear, even, unbroken curtains when the fans were off. However, as the fans were turned on, the low momentum laminar curtains were easily deflected. Possibly, thick laminar curtains would not deflect as much. It must be kept in mind, however, that the curtain momentum is proportional to U squared, and is directly proportional to b. In other words, if the curtain velocity is reduced by half, the curtain thickness must be increased by a factor of four to give the same momentum flux.

The fifth observation stated that the water curtain system behaves in a non linear manner. Because of this non linearity and the obvious complexity in the functional relationships, it is very difficult to use the present results to predict the performance of the full-scale system. This includes both the pressure differential and the pump and fan flow rates. Further study using a larger scale test rig is necessary to determine such things as required fan and pump power for a given curtain pressure differential.

5.0 CONCLUSIONS

The following conclusions have been made based on the results of the small scale tests.

1) The water curtain concept can support considerable pressures.

2) As the curtain L/b ratio is increased (decrease curtain thickness or increase curtain height), the curtain pressure differential decreases because of increased air leakage through the curtain.

3) As the curtain velocity is increased, the pressure differential increases due to the increased jet momentum.

4) As the level of turbulence in the curtain increases, air entrainment causes curtain breakup and increased air leakage.

5) The system behaves non linearly, and similarity principles do not seem to apply in any obvious form.

6.0 RECOMMENDATIONS

It is recommended that the water curtain concept be studied further using a larger scale test stand. The test stand should be designed to include the following features.

i) a wider curtain so that end effects (three dimensional effects) can be eliminated

ii) the rig should be designed so that it can be used to investigate both thin, high velocity curtains and thick, low velocity (laminar) curtains

A larger scale test rig will allow for more exhaustive experimentation. Results from such tests, coupled with the results from the small scale tests, will make accurate full-scale performance predictions possible.

APPENDIX A

Log Sheets and Computer Printouts

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SUBJECT	JOB NO.
WATER CURTAIN	82-153
	ORIGINATOR PCC
	DATE / PC.

WATER CURTAIN-SCALE MODEL TESTS

NOZZLE PRESSURE			FAN VOLTAGE 1/4 F.S.	1/2 F.S.	3/4 F.S.	FULL
	OFF	P_w	+ 0.	+ 0.	+ 0.	+ 0.
		ΔP_c	+.20	+.66	+1.07	+1.64
	2 PSIG	P_w	+ 2.	+ 2.	+ 1.9	+ 2 0
		ΔP_c	+1.01	+2.04	+ 2.30	+ 2.97
	5 PSIG.	P_w	+ 5.	+ 5.	+ 5.	+ 5
		ΔP_c	+ 1.10	+ 2.15	+ 2.72	+ 3.48
	10. PSIG.	P_w	+ 10.	+ 10.2	+ 10.	+ 10.2
		ΔP_c	+ 1.46	+ 2 65	+ 3.34	+ 4.2(
	FULL	P_w	+ 19.2	+ 19.	+ 19.2	+ 19.2
		ΔP_c	+ 1.56	+ 3.11	+ 4.12	+ 5.50

HEIGHT of CURTAIN $1\frac{1}{4}$ IN.

WIDTH of SLOT .010 IN.

ALL PRESSURES QUOTED IN INCHES WATER GAUGE (ΔP_c) AND PSIG (P_w)

MAX FAN VOLTAGE 118 V

MAX NOZZLE PRESS. 19 PSIG

GAP (INCHES) = 0.01000

CURTAIN HEIGHT (INCHES) = 1.25

0.000	0.000	0.000	0.000
0.200	0.660	1.070	1.640
2.000	2.000	1.900	2.000
1.010	2.040	2.300	2.970
5.000	5.000	5.000	5.000
1.100	2.150	2.720	3.490
10.000	10.200	10.000	10.200
1.460	2.650	3.340	4.260
19.200	19.000	19.200	19.200
1.560	3.110	4.120	5.500

0.00000	0.00000	0.00000	0.00000	
0.00000	0.00000	0.00000	0.00000	
0.00000	0.00000	0.00000	0.00000	
0.00000	0.00000	0.00000	0.00000	
0.00000	0.00000	0.00000	0.00000	
0.00000	0.00000	0.00000	0.00000	
17.24038	17.24038	16.80385	17.24038	U
996.49992	996.49992	973.79993	996.49992	Reb
112062.48437	112062.48437	109225.00000	112062.48437	ReL
135.62642	231.06725	208.95119	220.69816	ΔPc
0.00731	0.01246	0.01169	0.01201	$\Delta Pc/\rho U^2$
0.91406	1.55729	1.46107	1.50087	$\frac{\Delta Pc}{\rho U^2}\frac{L}{b}$
27.25944	27.25944	27.25944	27.25944	
1417.49060	1417.49060	1417.49060	1417.49060	
177186.32812	177186.32812	177186.32812	177186.32812	
150.69600	249.48564	276.27597	339.09960	
0.00325	0.00538	0.00596	0.00664	
0.40625	0.67257	0.74479	0.83058	
38.55067	39.93427	38.55067	39.93427	
2004.63452	2024.58179	2004.63452	2024.58179	
250579.32812	253072.73437	250579.32812	253072.73437	
210.97441	333.20560	380.38884	438.69291	
0.00227	0.00352	0.00410	0.00464	
0.28437	0.44033	0.51243	0.57972	
53.41737	53.13843	53.41737	53.41737	
2777.70264	2763.19800	2777.70264	2777.70264	
347212.84375	345399.75000	347212.84375	347212.84375	
227.71840	410.22800	510.69199	644.31942	
0.00129	0.00233	0.00287	0.00363	
0.15987	0.29103	0.35853	0.45374	

Davis Engineering
Consulting Engineers

SUBJECT	JOB NO. 82-153	
WATER CURTAIN	ORIGINATOR PCC	
	DATE	PC.

WATER CURTAIN-SCALE MODEL TESTS

NOZZLE PRESSURE			FAN VOLTAGE 1/4 F.S.	1/2 F.S.	3/4 F.S.	FULL
	OFF	P_w	0.	0.	0.	0.
		ΔP_c	+.05	+.15	+.27	+.47
	2 PSIG	P_w	2.	+1.9	+2.0	+2.0
		ΔP_c	+.44	+.72	.96	+1.25
	5 PSIG.	P_w	+5.	+5.	+5.1	+5.1
		ΔP_c	+.51	+.85	+1.16	+1.53
	10. PSIG.	P_w	+10.	+10.	+10.	+10.
		ΔP_c	+.62	+1.05	+1.38	+1.84
	FULL	P_w	+18.	+18.2	+18.	+17.8
		ΔP_c	+.77	+1.38	+1.82	+2.42

HEIGHT of CURTAIN 3 IN.

WIDTH of SLOT .010 IN.

ALL PRESSURES QUOTED IN INCHES WATER GAUGE

MAX FAN VOLTAGE 118 V

MAX NOZZLE PRESS. 19 PSIG

GAP (INCHES) = 0.01000

CURTAIN HEIGHT (INCHES) = 3.00

0.000	0.000	0.000	0.000
0.050	0.150	0.270	0.470
2.000	1.900	2.000	2.000
0.440	0.720	0.960	1.250
5.000	5.000	5.100	5.100
0.510	0.850	1.160	1.530
10.000	10.000	10.000	10.000
0.620	1.050	1.380	1.940
18.000	18.200	18.000	17.800
0.770	1.380	1.820	2.420

0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000

17.24038	16.80385	17.24038	17.24038
896.49982	873.79993	896.49982	896.49982
268949.96875	262140.00000	268949.96875	268949.96875
65.30160	95.44080	115.53361	130.60321
0.00352	0.00542	0.00623	0.00704
1.05625	1.62500	1.86875	2.11250

27.25944	27.25944	27.53068	27.53068
1417.49060	1417.49060	1431.59534	1431.59534
425247.18750	425247.18750	429478.62500	429478.62500
77.02241	117.20801	149.02161	177.48640
0.00166	0.00253	0.00315	0.00375
0.49833	0.75833	0.94526	1.12582

38.55067	38.55067	38.55067	38.55067
2004.63452	2004.63452	2004.63452	2004.63452
601390.43750	601390.43750	601390.43750	601390.43750
95.44080	150.69601	185.85841	229.39281
0.00103	0.00163	0.00200	0.00247
0.30875	0.48750	0.60125	0.74208

51.72115	52.00769	51.72115	51.43300
2689.49951	2704.39966	2689.49951	2674.51587
806849.87500	811320.00000	806849.87500	802354.81250
120.55680	205.95122	259.53201	326.50800
0.00072	0.00122	0.00155	0.00198
0.21667	0.36607	0.46644	0.59340

Davis Engineering
Consulting Engineers

SUBJECT	JOB NO.
WATER CURTAIN	82-153
	ORIGINATOR PCC
	DATE JAN 26/84 PC.

WATER CURTAIN-SCALE MODEL TESTS

NOZZLE PRESSURE			FAN VOLTAGE 1/4 F.S.	1/2 F.S.	3/4 F.S.	FULL
	OFF	P_w	+ 0.	+ 0.	+ 0.	+ 0.
		ΔP_c	+ .25	+ .80	+ 1.16	+ 1.86
	1/4	P_w	+1.	+1.1	+ 1.1	+1.1
		ΔP_c	+1.05	+1.73	+2.20	+2.98
	1/2	P_w	+3.	+3	+3.	+3.
		ΔP_c	+1.50	+2.40	+3.18	+4.04
	3/4	P_w	+7.2	+7.2	+7.1	+7.3
		ΔP_c	+1.98	+3.55	+434	+6.25
	FULL	P_w	+13.5	+13.5	+13.5	+13.5
		ΔP_c	+2.14	+3.83	+5.04	+7.04

HEIGHT of CURTAIN $1\frac{1}{4}$ IN.

WIDTH of SLOT .020 IN.

SUPPLY PRESSURE IN PSI(G)
PRESSURE DROPS QUOTED IN INCHES WATER GAUGE

MAX FAN VOLTAGE 118 V

MAX NOZZLE PRESS. 13 PSIG

GAP (INCHES) = 0.02000

CURTAIN HEIGHT (INCHES) = 1.25

0.000	0.000	0.000	0.000
0.250	0.800	1.160	1.860
1.000	1.100	1.100	1.100
1.050	1.730	2.200	2.980
3.000	3.000	3.000	3.000
1.500	2.400	3.180	4.040
7.200	7.200	7.100	7.300
1.980	3.550	4.340	6.250
13.500	13.500	13.500	13.500
2.140	3.930	5.040	7.000

0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000

12.19079	12.78581	12.78581	12.78581
1267.84229	1329.72412	1329.72412	1329.72412
79240.14062	83107.75781	83107.75781	83107.75781
133.95201	155.71921	174.13757	192.63291
0.01444	0.01527	0.01707	0.01919
0.90278	0.95407	1.06692	1.19995

21.11507	21.11507	21.11507	21.11507
2195.96704	2195.96704	2195.96704	2195.96704
137247.95312	137247.95312	137247.95312	137247.95312
209.30002	267.90399	338.22876	365.01926
0.00752	0.00963	0.01216	0.01312
0.47020	0.60185	0.75984	0.82002

32.71132	32.71132	32.48337	32.93771
3401.97729	3401.97729	3378.27002	3425.82129
212623.59375	212623.59375	211141.87500	214095.07812
299.67117	460.45999	532.45917	735.06165
0.00434	0.00690	0.00809	0.01096
0.27115	0.43101	0.50543	0.67863

44.79183	44.79183	44.79183	44.79183
4658.34961	4658.34961	4658.34961	4658.34961
291146.87500	291146.87500	291146.87500	291146.87500
316.46161	507.34323	649.66724	867.33923
0.00253	0.00405	0.00519	0.00693
0.15799	0.25328	0.32433	0.43309

Davis Engineering
Consulting Engineers

SUBJECT	WATER CURTAIN

JOB NO.	82-153	
ORIGINATOR	PCC	
DATE		PC.

WATER CURTAIN-SCALE MODEL TESTS

NOZZLE PRESSURE			FAN VOLTAGE 1/4 F.S.	1/2 F.S.	3/4 F.S.	FULL
	OFF	P_w	0.	0.	0.	0.
		ΔP_c	+.05	+.17	+.28	+.51
	1/4	P_w	+1.	+1.	+1.	+1.
		ΔP_c	+.35	+.59	+.79	+1.06
	1/2	P_w	+3.	+3.	+3.	+3.
		ΔP_c	+.55	+.94	+1.22	+1.58
	3/4	P_w	+7.25	+7.2	+7.2	+7.2
		ΔP_c	+.62	+1.18	+1.60	+2.22
	FULL	P_w	+13.25	+13.5	+13.5	+13.5
		ΔP_c	+.70	+1.25	+1.80	+2.58

HEIGHT of CURTAIN 3 IN.

WIDTH of SLOT .020 IN.

SUPPLY PRESSURE IN PSI(G)
PRESSURE DROPS QUOTED IN INCHES WATER GAUGE

MAX FAN VOLTAGE 118 V

MAX NOZZLE PRESS. 19 PSIG

GAP (INCHES) = 0.02000

CURTAIN HEIGHT (INCHES) = 3.00

0.000	0.000	0.000	0.000
0.050	0.170	0.280	0.510
1.000	1.000	1.000	1.000
0.350	0.590	0.790	1.060
3.000	3.000	3.000	3.000
0.550	0.940	1.220	1.580
7.200	7.200	7.200	7.200
0.620	1.180	1.600	2.220
13.200	13.500	13.500	13.500
0.700	1.250	1.800	2.580

0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000

12.19079	12.19079	12.19079	12.19079
1267.84229	1267.84229	1267.84229	1267.84229
190176.34375	190176.34375	190176.34375	190176.34375
50.23201	70.32480	95.39440	92.09200
0.00542	0.00758	0.00921	0.00993
0.81250	1.13750	1.38125	1.48958

21.11507	21.11507	21.11507	21.11507
2195.96704	2195.96704	2195.96704	2195.96704
329395.09375	329395.09375	329395.09375	329395.09375
83.71999	128.92880	157.39360	179.16080
0.00301	0.00463	0.00566	0.00644
0.45139	0.69514	0.84861	0.96597

32.71132	32.71132	32.71132	32.71132
3401.97729	3401.97729	3401.97729	3401.97729
510296.62500	510296.62500	510296.62500	510296.62500
95.44080	169.11440	221.02080	286.32239
0.00143	0.00253	0.00331	0.00429
0.21441	0.37992	0.49653	0.64323

44.29134	44.79183	44.79183	44.79183
4606.29980	4658.34961	4658.34961	4658.34961
690945.00000	698752.50000	698752.50000	698752.50000
108.83601	180.83521	254.50880	346.60077
0.00089	0.00144	0.00203	0.00277
0.13336	0.21667	0.30494	0.41528

Davis Engineering
Consulting Engineers

SUBJECT	JOB NO.
WATER CURTAIN	82-153
	ORIGINATOR Pcc
	DATE JAN 26/84 PC.

WATER CURTAIN-SCALE MODEL TESTS

NOZZLE PRESSURE			FAN VOLTAGE 1/4 F.S.	1/2 F.S.	3/4 F.S.	FULL
	OFF	P_w	+0.	+0.	+0.	+0.
		ΔP_c	+0.03	+0.09	+0.16	+0.26
	1/4	P_w	+1.	+1.	+1.	+1.
		ΔP_c	+0.20	+0.33	+0.45	+0.61
	1/2	P_w	+3.1	+3.2	+3.2	+3.2
		ΔP_c	+0.27	+0.44	+0.60	+0.84
	3/4	P_w	+7.0	+7.1	+7.2	+7.0
		ΔP_c	+0.30	+0.52	+0.71	+0.99
	FULL	P_w	+13.	+12.5	+12.5	+13.2
		ΔP_c	+0.34	+0.59	+0.65	+1.16

HEIGHT of CURTAIN 5 IN.

WIDTH of SLOT .020 IN.

SUPPLY PRESSURE IN PSI(G)
PRESSURE DROPS QUOTED IN INCHES WATER GAUGE

MAX FAN VOLTAGE 118 V

MAX NOZZLE PRESS. 13 PSIG

GAP (INCHES) = 0.02000

CURTAIN HEIGHT (INCHES) = 4.50

0.000	0.000	0.000	0.000
0.030	0.090	0.150	0.260
1.000	1.000	1.000	1.000
0.200	0.330	0.450	0.610
3.100	3.200	3.200	3.200
0.270	0.440	0.600	0.840
7.000	7.100	7.200	7.000
0.300	0.520	0.710	0.990
13.000	12.500	12.500	13.200
0.340	0.590	0.850	1.160

0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000

12.19079	12.19079	12.19079	12.19079
1267.84229	1267.84229	1267.84229	1267.84229
285264.50000	285264.50000	285264.50000	285264.50000
29.46480	40.19560	49.55760	59.60400
0.00307	0.00433	0.00534	0.00632
0.69063	0.97500	1.17913	1.42196

21.46410	21.80755	21.80755	21.80755
2232.26636	2267.98511	2267.98511	2267.98511
502260.00000	510296.65625	510296.65625	510296.65625
40.19560	58.60400	73.67360	91.11520
0.00140	0.00197	0.00248	0.00307
0.31452	0.44434	0.55854	0.69063

32.25380	32.48337	32.71132	32.25380
3354.39526	3378.27002	3401.97729	3354.39526
754739.00000	760110.81250	765445.00000	754739.00000
45.20980	71.99920	92.09201	122.23119
0.00070	0.00109	0.00138	0.00180
0.15670	0.24604	0.31033	0.42366

43.95452	43.10096	43.10096	44.29134
4571.26953	4482.49951	4482.49951	4608.29980
1028535.81250	1008562.37500	1008562.37500	1036417.43750
51.90639	83.71999	92.04560	150.69601
0.00043	0.00072	0.00071	0.00123
0.09688	0.16250	0.15925	0.27699

Davis Engineering
Consulting Engineers

SUBJECT	JOB NO.	
WATER CURTAIN	82-153	
	ORIGINATOR PCC	
	DATE JAN 27/83	PC.

WATER CURTAIN-SCALE MODEL TESTS

NOZZLE PRESSURE			FAN VOLTAGE			
			1/4 F.S.	1/2 F.S.	3/4 F.S.	FULL
	OFF	P_w	+0.	+0.	+0.	+0.
		ΔP_c	+.26	+.77	+1.22	+1.86
	1/4 (0.5)	P_w	+0.5	+0.5	+0.5	+0.5
		ΔP_c	+1.22	+1.90	+2.58	+3.42
	1/2 (2.5)	P_w	+2.5	+2.5	+2.5	+2.5
		ΔP_c	+1.70	+2.50	+3.10	+4.10
	3/4	P_w	+5	+5	+5	+4.9
		ΔP_c	+1.96	+3.44	+4.22	+5.20
	FULL	P_w	+9.6	+9.6	+9.6	+9.6
		ΔP_c	+2.14	+3.90	+4.87	+6.80

HEIGHT of CURTAIN 1 1/4 IN.

WIDTH of SLOT .032 IN.

SUPPLY PRESSURE IN PSI(G)
PRESSURE DROPS QUOTED IN INCHES WATER GAUGE

MAX FAN VOLTAGE 118 V

MAX NOZZLE PRESS. 10 PSIG

GAP (INCHES) = 0.03200

CURTAIN HEIGHT (INCHES) = 1.25

0.000	0.000	0.000	0.000
0.260	0.770	1.220	1.960
0.500	0.500	0.500	0.500
1.220	1.900	2.590	3.420
2.500	2.500	2.500	2.500
1.700	2.500	3.100	4.100
5.000	5.000	5.000	4.900
1.960	3.440	4.220	5.200
9.600	9.600	9.600	9.600
2.140	3.900	4.870	6.800

0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000

8.62019	8.62019	8.62019	8.62019
1434.39966	1434.39966	1434.39966	1434.39966
56031.24219	56031.24219	56031.24219	56031.24219
160.74240	189.20721	227.71939	281.20605
0.03467	0.04081	0.04911	0.06033
1.35417	1.59397	1.91840	2.35652

19.27533	19.27533	19.27533	19.27533
3207.41528	3207.41528	3207.41528	3207.41528
125299.66406	125299.66406	125299.66406	125299.66406
241.11362	299.67120	314.78723	375.06564
0.01040	0.01249	0.01358	0.01618
0.40625	0.48906	0.53039	0.63196

27.25944	27.25944	27.25944	26.98547
4535.96973	4535.96973	4535.96973	4490.38086
177186.32812	177186.32812	177186.32812	175405.51562
284.64801	447.06485	502.32001	559.24963
0.00614	0.00964	0.01083	0.01231
0.23990	0.37663	0.42318	0.48075

37.77179	37.77179	37.77179	37.77179
6285.22363	6285.22363	6285.22363	6285.22363
245516.57812	245516.57812	245516.57812	245516.57812
314.79723	524.09728	611.15607	827.15369
0.00354	0.00589	0.00686	0.00929
0.13812	0.22996	0.26816	0.36293

Davis Engineering
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SUBJECT	WATER CURTAIN

JOB NO.	82-153	
ORIGINATOR	PCC	
DATE	JAN 27/83	PC.

WATER CURTAIN-SCALE MODEL TESTS

NOZZLE PRESSURE			FAN VOLTAGE 1/4 F.S.	1/2 F.S.	3/4 F.S.	FULL
	OFF	P_w	+0.	+0.	+0.	+0.
		ΔP_c	+.05	+.18	+.32	+.52
	1/4	P_w	+0.5	+0.5	+0.6	+0.5
		ΔP_c	+.42	+.69	+0.86	+1.16
	1/2	P_w	+2.6	+2.6	+2.5	+2.5
		ΔP_c	+.58	+1.00	+1.32	+1.70
	3/4	P_w	+5.	+5.	+5	+5
		ΔP_c	+.67	+1.18	+1.66	+2.18
	FULL	P_w	+9.5	+9.5	+9.2	+9.6
		ΔP_c	+.80	+1.45	+2.00	+2.86

HEIGHT of CURTAIN 3 IN.

WIDTH of SLOT .032 IN.

SUPPLY PRESSURE IN PSI(G)
PRESSURE DROPS QUOTED IN INCHES WATER GAUGE

MAX FAN VOLTAGE 118 V

MAX NOZZLE PRESS. 10 PSIG

GAP (INCHES) = 0.03200

CURTAIN HEIGHT (INCHES) = 3.00

0.000	0.000	0.000	0.000
0.050	0.180	0.320	0.520
0.500	0.500	0.600	0.500
0.420	0.690	0.860	1.160
2.600	2.600	2.500	2.500
0.580	1.000	1.320	1.700
5.000	5.000	5.000	5.000
0.670	1.180	1.660	2.190
9.500	9.500	9.200	9.600
0.800	1.450	2.000	2.860

0.00000	0.00000	0.00000	0.00000	
0.00000	0.00000	0.00000	0.00000	
0.00000	0.00000	0.00000	0.00000	
0.00000	0.00000	0.00000	0.00000	
0.00000	0.00000	0.00000	0.00000	
0.00000	0.00000	0.00000	0.00000	
8.62019	8.62019	9.44295	8.62019	U
1434.39966	1434.39966	1571.30591	1434.39966	Reb
134474.98437	134474.98437	147309.93750	134474.98437	ReL
61.95280	85.39441	90.41762	107.16161	ΔPc
0.01336	0.01842	0.01625	0.02311	$\Delta Pc/\rho U^2$
1.25260	1.72656	1.52344	2.16667	$\Delta Pc/\rho U^2$ L/b
19.65706	19.65706	19.27533	19.27533	
3270.93433	3270.93433	3207.41528	3207.41528	
306650.12500	306650.12500	300695.21875	300695.21875	
88.74320	137.30081	167.44000	197.57921	
0.00368	0.00569	0.00722	0.00852	
0.34505	0.53385	0.67709	0.79896	
27.25944	27.25944	27.25944	27.25944	
4535.96973	4535.96973	4535.96973	4535.96973	
425247.18750	425247.18750	425247.18750	425247.18750	
103.81279	167.43999	224.36961	277.95041	
0.00224	0.00361	0.00484	0.00599	
0.20990	0.33854	0.45365	0.56198	
37.57454	37.57454	36.97650	37.77179	
6252.40332	6252.40332	6152.89919	6285.22363	
586162.87500	586162.87500	576833.43750	589239.75000	
125.57999	212.64880	291.29922	391.80963	
0.00143	0.00241	0.00330	0.00440	
0.13363	0.22629	0.30910	0.41260	

Davis Engineering
Consulting Engineers

SUBJECT	WATER CURTAIN

JOB NO.	82-153	
ORIGINATOR	PCC	
DATE	JAN 27/83	PC.

WATER CURTAIN-SCALE MODEL TESTS

NOZZLE PRESSURE			FAN VOLTAGE 1/4 F.S.	1/2 F.S.	3/4 F.S.	FULL
	OFF	P_w	+0.	+0	+0.	+0
		ΔP_c	+.03	+.09	+.16	+.27
	1/4	P_w	+0.4	+0.4	+0.5	+0.6
		ΔP_c	+0.22	+0.35	+0.49	+0.65
	1/2	P_w	+2.5	+2.5	+2.5	+2.5
		ΔP_c	+0.30	+0.47	+0.63	+0.87
	3/4	P_w	+5.1	+5.1	+5.3	+5.3
		ΔP_c	+0.38	+0.55	+0.76	+1.05
	FULL	P_w	+9.5	+9.1	+9.5	+9.5
		ΔP_c	+.48	+0.66	+0.87	+1.20

HEIGHT of CURTAIN 5 IN.

WIDTH of SLOT 0.032 IN.

SUPPLY PRESSURE IN PSI(G)
PRESSURE DROPS QUOTED IN INCHES WATER GAUGE

MAX FAN VOLTAGE 118 V

MAX NOZZLE PRESS. 19 PSIG

GAP (INCHES) = 0.03200

CURTAIN HEIGHT (INCHES) = 4.50

0.000	0.000	0.000	0.000
0.030	0.090	0.160	0.270
0.400	0.400	0.500	0.600
0.220	0.350	0.490	0.650
2.500	2.500	2.500	2.500
0.300	0.470	0.630	0.870
5.100	5.100	5.300	5.300
0.380	0.550	0.760	1.050
9.500	9.100	9.500	9.500
0.480	0.660	0.870	1.200

0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000

7.71013	7.71013	9.62019	9.44295
1282.96594	1282.96594	1434.39966	1571.30591
180417.10937	180417.10937	201712.48437	220964.92197
31.81360	43.53440	55.25520	63.62720
0.00858	0.01174	0.01192	0.01144
1.20605	1.65039	1.67578	1.60807

19.27533	19.27533	19.27533	19.27533
3207.41528	3207.41528	3207.41528	3207.41528
451042.81250	451042.81250	451042.81250	451042.81250
45.20880	63.62720	78.69681	100.46401
0.00195	0.00274	0.00339	0.00433
0.27422	0.38594	0.47734	0.60938

27.53068	27.53068	28.06531	28.06531
4581.10498	4581.10498	4670.06641	4670.06641
644217.93750	644217.93750	656728.18750	656728.18750
58.60400	77.02239	100.46401	130.60321
0.00124	0.00163	0.00204	0.00266
0.17425	0.22901	0.28744	0.37367

37.57454	36.77499	37.57454	37.57454
6252.40332	6119.35791	6252.40332	6252.40332
879244.31250	860534.81250	879244.31250	879244.31250
75.34800	95.44080	118.88241	155.71919
0.00086	0.00113	0.00135	0.00177
0.12027	0.15904	0.18976	0.24858

APPENDIX B

Data Reduction Computer Program

```
C
      IMPLICIT REAL(A-Z)
      INTEGER I,J
C`
      DIMENSION PW(4,5),PC(4,5),REB(4,5),PRAT(4,5)
      DIMENSION REL(4,5),PCNET(4,5),U(4,5),PRATLB(4,5)
C
      CALL ASSIGN(1,'DL1:CURTAIN.DAT',0)
      CALL ASSIGN(2,'TT2:',0)
C
      WRITE(2,1233)
 1233 FORMAT('1')
      RHO = 62.4
      GC = 32.2
      G = 32.2
      VISC = 1.0E-03
C
      READ(1,8) GAP
      WRITE(2,10) GAP
 10   FORMAT( 5X,//,' GAP (INCHES) = ',F12.5,/)
      GAP = GAP/12.
      READ(1,8) H
      WRITE(2,20) H
 20   FORMAT( 5X,' CURTAIN HEIGHT (INCHES) = ',F12.2)
      H = H/12.
C
      DO 100 J = 1,5
      READ(1,8) PW(1,J),PW(2,J),PW(3,J),PW(4,J)
      READ(1,8) PC(1,J),PC(2,J),PC(3,J),PC(4,J)
      WRITE(2,30) PW(1,J),PW(2,J),PW(3,J),PW(4,J)
      WRITE(2,30) PC(1,J),PC(2,J),PC(3,J),PC(4,J)
 30   FORMAT( 5X,4F12.3)
 100  CONTINUE
      WRITE(2,1111)
 1111 FORMAT( 5X,///)
C
      DO 200 J = 1,5
      DO 200 I = 1,4
      PW(I,J) = PW(I,J)*144.*GC
      PC(I,J) = PC(I,J)/12.*RHO*G
 200  CONTINUE
C
      DO 300 J = 2,5
      DO 300 I = 1,4
      U(I,J) = SQRT(2.*PW(I,J)/RHO)
      REB(I,J) = RHO*U(I,J)*GAP/VISC
      REL(I,J) = RHO*U(I,J)*H/VISC
      PCNET(I,J) = PC(I,J) - PC(I,1)
      PRAT(I,J) = PCNET(I,J)/RHO/U(I,J)**2.
      PRATLB(I,J) = PRAT(I,J)*H/GAP
 300  CONTINUE
C
```

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```
      DO 400 J = 1,5
      WRITE(2,40) U(1,J),U(2,J),U(3,J),U(4,J)
      WRITE(2,40) REB(1,J),REB(2,J),REB(3,J),REB(4,J)
      WRITE(2,40) REL(1,J),REL(2,J),REL(3,J),REL(4,J)
      WRITE(2,40) PCNET(1,J),PCNET(2,J),PCNET(3,J),PCNET(4,J)
      WRITE(2,40) PRAT(1,J),PRAT(2,J),PRAT(3,J),PRAT(4,J)
      WRITE(2,40) PRATLB(1,J),PRATLB(2,J),PRATLB(3,J),PRATLB(4,J)
      WRITE(2,50)
 40   FORMAT( 5X,4F14.5)
 50   FORMAT( 5X,/)
 400  CONTINUE
C
      STOP
      END
```